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14. ABSTRACT
We further developed our interactive visualization for terrain change detection and investigated a broader range of data structures for probabilistic surface modeling. Detecting changes in LIDAR scans creates an overwhelming number of change models. These models should be grouped into meaningful higher level events. For example, a set of 100 removed trees grouped into a "deforestation" event. These events would provide a semantic index into the set of change models. Both computer and human analyses are needed to identify events. To help the user identify change objects, we integrate road and building permit data into the visualization. To allow the user to see change trends at any scale, we develop a three-tier,

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Theory and Application of an Eye-Point Dependent Metric for
Multiresolution Terrain Models
Interim Progress Report, August 31, 2007 through August 31, 2008

ABSTRACT

We further developed our interactive visualization for terrain change detection and investigated a broader range of data structures for probabilistic surface modeling. Detecting changes in LIDAR scans creates an overwhelming number of change models. These models should be grouped into meaningful higher level events. For example, a set of 100 removed trees grouped into a "deforestation" event. These events would provide a semantic index into the set of change models. Both computer and human analyses are needed to identify events. To help the user identify change objects, we integrate road and building permit data into the visualization. To allow the user to see change trends at any scale, we develop a three-tier, level-of-detail rendering algorithm. Finally, to show the distribution of change model size and to filter the displayed models, we develop an interactive heat-map that plots shape area versus height versus occurrence frequency. Our system does not use the permission grid data structure used in our prior work. We identified several problems with using this structure for change detection. We are examining non-computer graphics probabilistic surface models that are based on continuous, rather than binary, scalar fields. We are comparing these works' field datum and probabilistic metrics.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Thomas Butkiewicz, Remco Chang, Zachary Wartell, William Ribarsky. Visual Analysis and Semantic Exploration of Urban LIDAR Change Detection. EuroVis 2008 / Computer Graphics Forum, vol. 27, num. 3, 2008.

Thomas Butkiewicz, Wenwen Dou, Zachary Wartell, William Ribarsky, Remco Chang. Multi-Focused Geospatial Analysis Using Probes. InfoVis 2008 (IEEE Transactions on Visualization and Computer Graphics), to appear.

Number of Papers published in peer-reviewed journals: 2.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Thomas Butkiewicz, Remco Chang, Zachary Wartell, William Ribarsky. Visual Analysis for Live LIDAR Battlefield Change Detection. SPIE Defense and Security Symposium 2008, vol. 6983 pp. 69830B.

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):   1

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):   0

(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
Thomas Butkiewicz	1.00
FTE Equivalent:	**1.00**
Total Number:	**1**

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Zachary Wartell	0.08	No
William Ribarsky	0.08	No
FTE Equivalent:	**0.16**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics
This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

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Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME   PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Theory and Application of an Eye-Point Dependent Metric for Multiresolution Terrain Models

Interim Progress Report, August 31, 2007 through August 31, 2008

Executive Summary

The overall objectives of this project over its 3 year duration are as follows.

We are developing a general metric for multiresolution surface models. This metric can be applied to terrain height fields or to other, more general surface models. The proposed research will produce the following specific results.

- A multiresolution structure, efficient for both terrain analysis and interactive visualization, where there is a monotonic relation between the resolutions
- Analytic formulations for the error metrics connecting lower resolution models to both the highest resolution models and to neighboring resolutions
- An error metric expressed in terms of components such as maximum error, mean error and variance appropriate for a statistical or probabilistic analysis
- A feature-preserving simplification approach that is more accurate and effective than global approaches for relevant tasks
- Eye-point dependent simplification around a particular viewing direction and area of focus where there can be both local control and regional approximations
- Formulations of the error metric, feature preserving approach, and eye-point dependent simplification for both regular and irregular meshes.

This work will lead to an efficient multiresolution approach based on analytical metrics that will have important characteristics. These include the ability to quickly select a terrain model for viewing or analysis under a given error criterion or, conversely, to permit calculations at reduced resolution with a time goal (for time-critical situations) and with error outputs. In addition, terrain regions can be effectively selected for analysis with a computational effort proportional to the size of the region rather than the size of the whole terrain model.

Review of Prior Contract Periods

Simplification Procedure and Error Metric Formulation
Simplifications for irregular grid terrain models have been formulated in terms of a quadric-based vertex merge approach [Gar99]. The quadric-based formulation should produce, in principle, the best approximation at a given level of simplification. This is because it permits contraction of vertex pairs anywhere in their local region (not just along the edge between them) by minimizing the deviation and curvature of the simplified surface [Gar99].

Permission Grids and Simplification. Our initial work integrates Michael Garland's quadric error based simplification algorithms alongside Steven Zelinka's permission grid concept [Zel02]. We built a simple terrain explorer interface provides an interactive means for loading and viewing a terrain model, inspecting the permission grids, commanding simplification, and viewing the resulting approximations.

Zelinki et al. [Zel02] show how to use permission grids with Garland's QSlim quadric implementation in order to generate a simplified mesh in which all points on the approximation are guaranteed to be within some user-specified distance from the original surface. (This is the one-sided Hausdorff distance from the simplified surface to the original). However, the permission grid approach can be memory intensive because it is a voxelization of the original grid. Zelinki et al. suggest as future work to use some method for compressing the grid such as run-length encoding or octrees. We have implemented the Zelinka approach and have developed an octree based method to reduce storage requirements. This is a new contribution to the traditional use of Permission Grids. Additionally, the octree approach provides run-time access to

occupancy grids at multiple resolutions to allow user control over the tradeoff between accuracy and computation time in applications like line-of-sight analysis. Next, we developed a tertiary, edge preserving grid added to the octree to protect ridgelines, which produce the silhouettes that are crucial to differentiating visible and non-visible areas. This is in line with our premise to concentrate detail where it is needed. During simplification, each time a candidate edge is considered for contraction, the edges that would be affected are checked to see if they have been marked by a preservation grid (ridgeline, boundary edge, etc.) Any marked edges are checked against their corresponding grids to ensure they do not stray from their original locations by more than the set error allowance. Only edges that pass this test are allowed to be contracted. We have investigated the effects of data uncertainty in line-of-sight applications. We are using the Permission Grid approach to determine the bounds of the data uncertainty, and investigating Gernot Schaufler's Occluder Fusion [Sch00] for volumetric visibility.

The motivation behind developing an error-bounded line-of-sight application is that terrain data is never completely accurate in real life. By taking the errors into consideration, we will be able to give "confidence levels" line-of-sight results. We identified three different ways that error could be introduced into the data: data acquisition, data simplification and data discretization. Details are covered in [But06], but the basic idea is to allow the space of occupied voxels in the permission grid to grow larger as we move away from the original terrain sample locations indicating that the actually terrains locations is more uncertain as we move further from the known sample points (Figure 1A). The result in 3D is to generate a region of possible actually terrain location around the idealistic linear interpolated triangle between known sample points (Figure 1b)
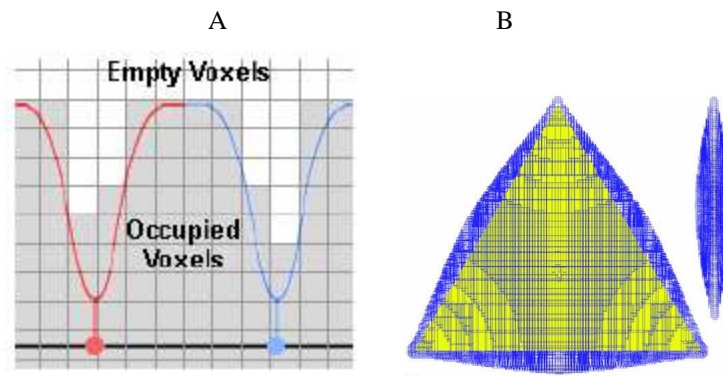
A   B

Figure 1

Line of Sight Analysis: We have incorporated the notion of time-critical error into our interactive LOS application. We briefly reported on preliminary aspects of this addition in our 2005-2006 interim report but we have now completed this integration and the full details are published in

In [But07a], we developed in interactive LoS application in which the user to interactively place and move units across large expanses of terrain while line-of-sight (LoS) visibility calculations are run within user specified time-limits. We calculate volumetric representations for the terrain, based on both the sampling techniques and geologic properties of the region. Each model is generated with a certainty measure that accounts for errors that may result from the sampling and modeling process. These models are represented hierarchically, which conserves memory, storage space, and processing time. Figure 2 shows the visibility output for a region-of-interest showing the voxels found to be invisible from the selected eye-point (the blue tank with the pink marker)
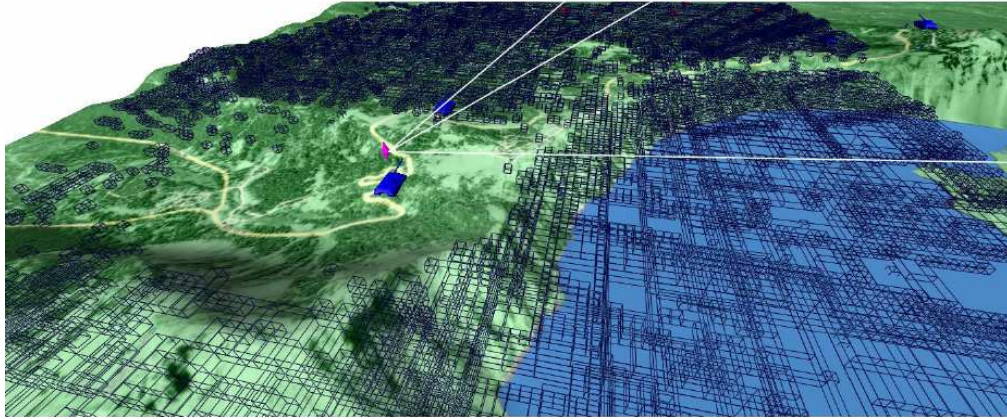
Figure 2: Example visibility output for a region-of-interest showing the voxels found to be invisible from the selected eye-point (the blue tank with the pink marker)

LIDAR Change Detection: A key aspect of the above work was modeling three different ways that error could be introduced into the terrain data: data acquisition, data simplification and data discretization. We have been applying these concepts to change detection across terrain LIDAR scans taken at different times. Several researchers have devised methods to detect changes between LIDAR point sets taken at different times for the purposes of locating demolished buildings or new construction. However these methods do not consider the uncertainties of the collection hardware and errors present in their datasets. We have developed a method for LIDAR change detection that accounts for errors in sample collection and model building, maintains accuracy, and extracts changes as independent 3D models. These change models are then utilized in an urban model supporting the chronological exploration of changes over a period of years (Figure 3). This work is detailed in [But07b].
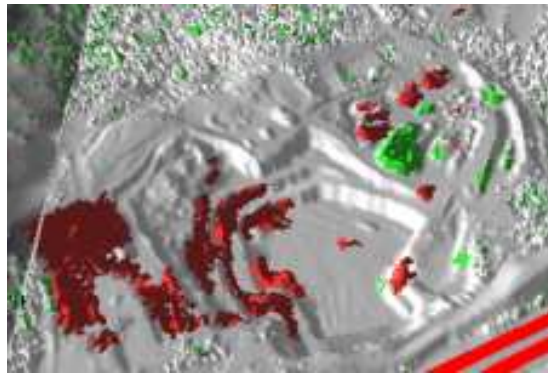

Figure 3: Shown here in dark red are the volumes of rock removed between 2002-2003 at a local quarry in Charlotte, NC.

Progress During Current Contract Period

In [But8a], we further develop our LIDAR change detection software. A three-tiered level-of-detail system maintains a scale-appropriate, legible visual representation across the entire range of view scales, from individual changes such as buildings and trees, to groups of changes such as new residential developments, deforestation, and construction sites, and finally to larger regions such as neighborhoods and districts of a city that are emerging or undergoing revitalization. Interactive tools are provided to assist visual analysis by urban planners and historians through semantic categorization and filtering of the changes presented.

When the user is zoomed in to a view that is significantly close to the terrain, the system shows the unaltered change models at full detail, as this allows for immediate inspection and interpretation of the change detection results (Figure 3). However, as the user zooms out, smaller change models quickly become little more than a pixel or disappear altogether. We counteract this problem with the introduction of

a second level-of-detail. As individual models recede away from the camera, they are gradually replaced by a semi-transparent 'splat' which is scaled to maintain near-constant screen-size. These splats seamlessly fade in while the individual model detail level fades out. The splats do not simply allow us to see individual changes/buildings beyond the point at which their models would disappear. They also provide an amalgamating behavior in which collections of individual changes cooperate to form larger, more significant glyphs in the visualization (Figure 4).
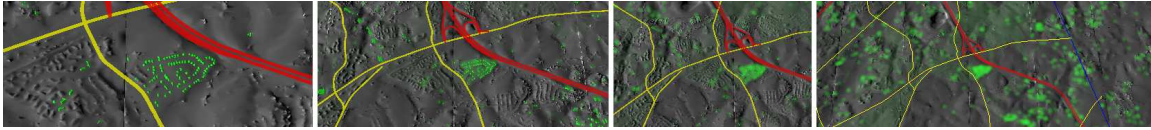

Figure 4: Transition from render change models to amalgamated splats.

The third and final level of abstraction is displayed when the user has zoomed out to a distance where depicting individual changes and even amalgamated groups in splat form no longer makes sense due to overlap and clutter. At this level, the system renders urban legibility regions. These regions are based on the level-of-detail clusters generated by Chang et al. [Cha08] which delineate sections of the city based on aspects of urban legibility, such as paths, districts, nodes, and other perceptual qualities. Originating from a LOD solution to city-viewing, these clusters are naturally useful to display city-wide data in clustered form at appropriate detail for a wide range of distances, as Chang et al. demonstrate with census data [Cha07]. Figure 5 illustrates a wide range of zoom levels over which the concentration of changes remain legible. These regions' shading can be determined by several criteria, such as the comparative ratios of local to global change footprint areas, the number of change points, or the number of individual changes.
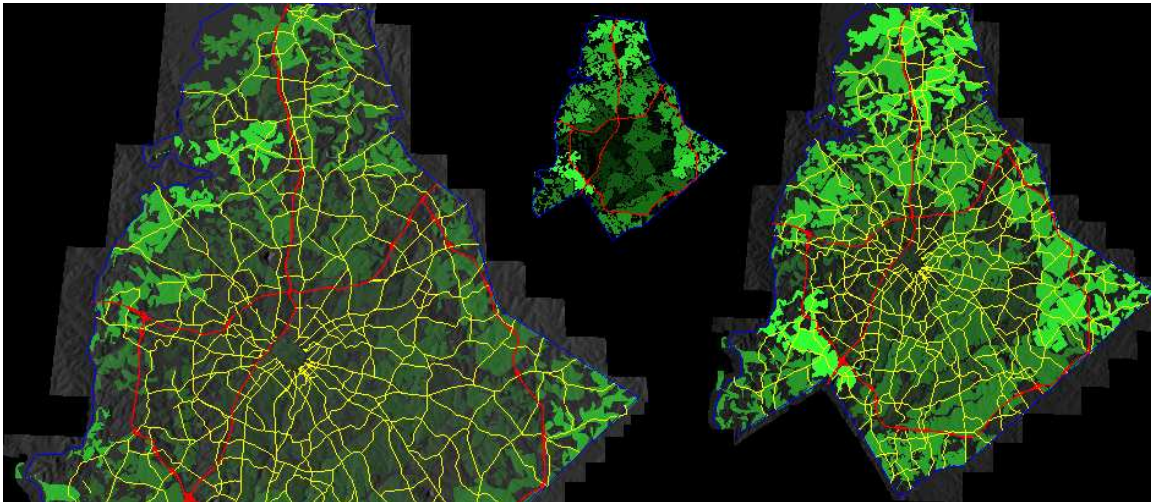

Figure 5: Geometric aggregation algorithm shows degree of terrain change over multiple levels of detail.

Finally, an interactive heat map (Figure 6) allows the user to further explore and filter change models based on the model's shape. The heat map's x-axis is the area of a change model's footprint while the y-axis is the height of a change model. The color intensity of each pixel in the heat map varies with the number of change models having that area and height value. Users can select regions in the heat-map to use as filters for controlling what change models are displayed. Several preset filters are available based on average measurements of common objects like trees (characteristically tall and skinny) and warehouses (characteristically wide and flat).

Such interactive rendering techniques and interactive tools are necessary to help the terrain analyst make sense of the large quantities of mesh data and the large quantities of extracted change models. In [But08c], we present a high-level framework for a software system allowing military analysts to coordinate and utilize live collection of LIDAR data. Our earlier experience with large collections of geospatial Doppler

weather radar [Jan02] lead us to conclude that ultimately a temporal, geospatial application which continuously gathers new data not only needs a multi-resolution, temporal spatial index but also a semantic index that stored identified subsets of the low-level geometric data as events with human understandable meaning such as "a bridge at location X,Y was destroyed at time T." The interactive filter provided by the heat map interface and inclusion of GIS data in the visualization allows the user to manually identify these higher level concepts of terrain change and is a first step towards being able to store them in a higher level event index.
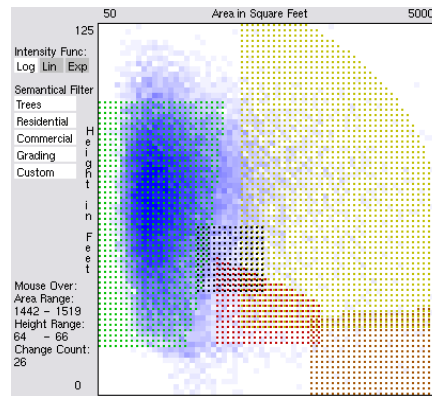

Figure 6: Interactive heat map. X-axis is the area of the footprint of detected change models; the y-axis is the height. Pixel intensity increases with large occurrences of models with the associated shape.

Our LIDAR change detection uses the error metrics that we developed for the earlier hierarchical permission grid and line-of-sight application; however our change detection algorithm does not currently use the permission grid itself. The terrain mesh LODs are calculated off-line using Q-Slim [Gar99] and as new data arrives the change detection algorithm uses the highest resolution meshes directly. Integrating the hierarchical permission grid into the change detection system has two aspects. First, we need to integrate a temporal component to the hierarchical permission grid to allow the permission grid to evolve over time. This would be used for extracting a simplified mesh at any point in time. The second aspect is using the permission grid for the change detection process. One difficulty with this is that the permission grid has inherent discretization error. If a new terrain vertex falls in a voxel that contained the original boundary of the error envelope, then the voxel occupancy alone could not give a exact answer to the question of whether the new vertex is within an error range. As we considered various tri-colored voxel approaches that might reduce this inaccuracy, we decided to further investigate alternative methods that use continuous scalar fields to represent surface error.

We are investigating volumetric spatial data structures and metrics used outside computer graphics, in robotics, remote sensing, and 3D artifact scanning. We are reviewing several extensions on occupancy grids [Elfes87], weighted distance fields [Curl96] [Hilton97] and surface probability functions [John02]. We are examining the detailed scalar field data and the probability equations used in these works. It appears rare for algorithms to combine simplification error, measurement error and interpolation error in a manner that yields simplified surfaces with an integrated error envelope. One exception, outside of our own work with permission grids, is the work of Cheung and Shi [Cheung04] that presents a 2D model for line simplification that provides a confidence region called an *integrated band*. We have yet to determine how these approaches, in whole or in part, might be immediately integrated into our current system and/or yield a hybrid approach that has the relative simplicity of permission grids and the greater sophistication of these other techniques' error models.

Publications
The following publications were accepted during this contract period:

[But08a]   Thomas Butkiewicz, Remco Chang, Zachary Wartell, William Ribarsky. Visual Analysis and Semantic Exploration of Urban LIDAR Change Detection. EuroVis 2008 / Computer Graphics Forum, vol. 27, num. 3, 2008. (PDF)

[But08b]   Thomas Butkiewicz, Wenwen Dou, Zachary Wartell, William Ribarsky, Remco Chang. Multi-Focused Geospatial Analysis Using Probes. InfoVis 2008 (IEEE Transactions on Visualization and Computer Graphics), to appear. (PDF)
[But08c]   Thomas Butkiewicz, Remco Chang, Zachary Wartell, William Ribarsky. Visual Analysis for Live LIDAR Battlefield Change Detection. SPIE Defense and Security Symposium 2008, vol. 6983 pp. 69830B. (manuscript PDF, figures PDF)

Technology Transfer
We had two projects that build on models and analyses derived in this project. One project was with the Charlotte Mecklenberg GIS Department to supply an interactive 3D model of the downtown Charlotte area. This model will be used for many planning and infrastructure applications. We continue to partner with the Charlotte Mecklenberg GIS group in data exchange and informal discussions. Next, our 3D models are being incorporated into an urban critical infrastructure system. This system does predictive simulations of how interrelated infrastructures such as electrical power, gas lines, water, telecommunications, and so on are affected by a breakdown at any point in any one of these infrastructures. Among other things, this urban model and simulation environment is being used on a joint project with the DHS National Visualization and Analytics Center. The project will simulate the entire Northwestern power grid, which covers a significant portion of the Northwest USA and Canada. Most recently, we received a grant form the DHS through the National Center of Excellence for the Study of Natural Disasters, Coastal Infrastructure and Emergency Management at UNC, Chapel Hill. Our LIDAR change detection system will provide a starting point for a visualization tool for examining the effects of flooding on coastal areas.

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But07b Thomas Butkiewicz, Remco Chang, William Ribarsky, and Zachary Wartell. "Visual Analysis of Urban Terrain Dynamics", In "Understanding Dynamics of Geographic Domains", May Yuan, Kathleen S. Hornsby. CRC Press/Taylor and Francis. 2007.
But08a   Thomas Butkiewicz, Remco Chang, Zachary Wartell, William Ribarsky. Visual Analysis for Live LIDAR Battlefield Change Detection. SPIE Defense and Security Symposium 2008, vol. 6983, pp. 69830B-.
But08b Thomas Butkiewicz, Remco Chang, Zachary Wartell, William Ribarsky. Visual Analysis and Semantic Exploration of Urban LIDAR Change Detection. EuroVis 2008 / Computer Graphics Forum, vol. 27, num. 3, 2008.
But08c Thomas Butkiewicz, Wenwen Dou, Zachary Wartell, William Ribarsky, Remco Chang. Multi-Focused Geospatial Analysis Using Probes. InfoVis 2008 (IEEE Transactions on Visualization and Computer Graphics), to appear. (PDF)
Cha06   Remco Chang, Thomas Butkiewicz, Zachary Wartell, Nancy S. Pollard, William Ribarsky, "Hierarchical Simplification of City Models to Maintain Urban Legibility", Proceedings of the SIGGRAPH 2006 Conference on Sketches, Aug. 2006, Boston, MA, ACM Press.
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